Safer or Cheaper? Household Safety Concerns, Vehicle Choices, and the Costs of Fuel Economy Standards

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Introduction

Growing concerns over the environmental externalities of greenhouse gas emissions have heightened the interest of environmental groups and government demanding increases in vehicle fuel efficiency. Fuel efficiency regulations were first introduced in 1975 in the form of the Corporate Average Fuel Economy (CAFE) standards, expressed in miles per U.S. gallon, and the standards are getting stringent over time. In 2011, President Obama announced an agreement with thirteen large automakers to increase fuel economy to 54.5 miles per gallon for cars and light-duty trucks by model year 2025, a jump from the previous standard for all vehicles of 35.5 MPG (Figure 1).

To meet the tougher rules phasing in, around 50% of automakers are focused on light weighting and use of lightweight structural materials on their new products as other technologies will soon be unable to propel the industry's profess in meeting tougher requirements (Wards Auto, 2014). On the other hand, it is generally believed that the decrease in vehicle weight due to higher fuel economy standard is correlated with increases in vehicle fatalities (Crandall and Graham, 1989). Responding to the criticism that the CAFE may increase traffic safety risks, the reformed CAFE standards in 2008 introduced footprint-based standards such that manufacturers that produce larger so heavier vehicles can meet lower fuel economy standards (Figure 1). And since consumers have heterogeneous preference on vehicles' attributes and safety concerns, one might wonder how the increasing fuel economy standards will affect consumer's vehicle choices and consumer welfare.

Figure 1

History of CAFE

1975
- The Energy Policy Conservation Act
- Established the first Corporate Average Fuel Economy (CAFE) standards
- For passenger cars and light-duty trucks
- 1974 – MY 1985

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2007
- Energy Independence and Security Act (EISA)
- Introduced CAFE and GHG Emission Standards
- Effective for MY2011 – MY 2020

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2008
- Reformed CAFE Standards
- Adopted for light trucks
- First introduced a standard based on “footprint” value
- Effective after 2011- (During a transition period 2008 – 2010, manufacturers had the choice of complying either with the unreformed CAFE Standards or with the reformed CAFE Standards)

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2010
- Finalized new, harmonized CAFE and GHG Emission Standards
- Effective for MY 2012 – MY 2016
- Based on CO2 emissions-footprint curves
- A complicated formula of the reformed CAFE was replaced with a simpler inverse-linear formula with cut-off values

↓

2012
- Extended the harmonized CAFE and GHG Emission Standards
- Finalized in 2012 as a result of “2011 agreement” President Obama announced on July 29 2011
- Effective for MY 2017 – MY 2025

There are some literatures that have examined several issues of consumer’s vehicle choice related to fuel efficiency and traffic safety. Li (2012) analyzes the effect of traffic safety on vehicle demand using a random-coefficient discrete-choice model to quantify the effects of light trucks’ arms race on vehicle demand, producer performance and traffic safety. The results show that consumers are willing to pay a premium for the safety advantage of light trucks. Whitefoot & Skerlos (2012) conduct simulations using an oligopolistic equilibrium model to examine if the new footprint-based CAFE standards will provide automakers with an incentive to increase vehicle size. The results suggest that the new CAFE standards create an incentive to increase vehicle size unless consumer preference for vehicle size is above its lower bound and preference for acceleration is below its upper bound.

In this paper, we first formulate and estimate a mixed logit model of consumer vehicle choices with micro-level data to examine the effect of safety concern on their vehicle choices, especially on the preference for various vehicle characteristics linked to vehicle safety (MPG, weight, size, etc). Further, using the demand estimates, we simulate consumers' vehicle choices under alternative fuel economy standards that will result in new product offerings from automakers. We then calculate and compare the welfare change for consumers with different safety concerns.

Methodology

A mixed-logit (random-parameters logit) of consumers' demand in vehicles is estimated to capture their preference between safety and fuel efficiency. The model allows a coefficient of each observed variable to vary randomly across consumers rather than being fixed so that different consumers have different tastes for each factor in the model (Train 1998, Revelt & Train 1997).

Suppose the utility of consumer n from choosing alternative j ∈ J is specified as

$$U_{nj} = \alpha_n p_j + \beta x_j + \gamma S_n x_j + \delta F_n x_j + \epsilon_{nj}$$

where p_j is the price of vehicle j, x_j is a vector of observed variables of choice alternatives such as horsepower, weight, footprint, MPG, vehicle type and origin. $S_n x_j$ is a vector of interaction terms of vehicle characteristics and the consumer's view on safety concerns, and $F_n x_j$ is another vector of interaction terms of vehicle characteristics and fatalities of the state where the consumer lives. ϵ_{nj} is an unobserved random error term with i.i.d. extreme value distribution.

Note that the coefficient α_n is a random coefficient for price to capture the heterogeneity of consumer taste. That is, it is assumed to vary over consumers in the population with density f: $\alpha_n \sim f(\alpha|\theta)$, where θ is a vector of mean and variance. We also assume that α_n follows an independent lognormal distribution since price is expected to have same sign for all consumers with magnitude varying over consumers. Lognormal distribution results in a positive impact of price on all consumers' demand, so the negative of price is taken in the model for estimation.

If we knew consumer's individual taste, by taking advantage of the i.i.d. extreme value distribution of ϵ_{nj}, the probability that consumer n chooses vehicle i, conditioning on α_n, can be calculated by:

$$L_{ni}(\alpha_n) = \frac{\exp(\alpha_n p_i + \beta x_i + \gamma S_n x_i + \delta F_n x_i)}{\sum_j \exp(\alpha_n p_j + \beta x_j + \gamma S_n x_j + \delta F_n x_j)}$$

However, since α_n is actually unknown and random, the unconditional choice probability is the integral of $L_{ni}(\alpha_n)$ over all possible variables of α_n:

$$P_{ni} = \int \left(\frac{\exp(\alpha_n p_i + \beta x_i + \gamma S_n x_i + \delta F_n x_i)}{\sum_j \exp(\alpha_n p_j + \beta x_j + \gamma S_n x_j + \delta F_n x_j)} \right) f(\alpha_n|\theta) \mathrm{d}\alpha_n$$

Since the probability P_{ni} does not have a closed for solution, a maximum simulated likelihood method is used for estimation (Train, 2003). The simulated log likelihood is then given by:

$$\mathrm{SLL} = \sum_{n=1}^{N} \sum_{i=1}^{J} d_{ni} ln \check{P}_{ni}(\theta)$$

Where $d_{ni} = 1$ if consumer n choose product i and zero otherwise, and $P_{ni}^{\vee}(\theta)$ is the average simulated probability. The maximum simulated likelihood estimator is the value of θ that maximizes SLL.

Data

This analysis combines datasets from several sources. The dataset used for variables of households' vehicle choice, demographic information and safety concerns is the 2009 National Household Travel Survey (NHTS) obtained from U.S. Department of Transportation, Federal Highway Administration. The NHTS is a cross-sectional survey of the civilian, non-institutionalized populations of the United States conducted over a period from March 2008 through May 2009. The dataset contains data for 150,147 household in the sample including household's total income ($), size, location according to political geographic divisions and best estimate of annual miles, vehicle's make and model and respondent's view on safety concerns (U.S. Department of Transportation Federal Highway Administration 2011). The data on vehicle characteristics such as price ($), horsepower, weight (vehicle curb weight, lbs.), wheelbase (inch), front/rear track width (inch), fuel economy (45/55, miles per gallon), class (passenger, SUV/van, light truck) and origin (US, Europe, Asia) is collected from the WARD's Automotive Yearbook and Edmund.com. State level fatalities data is obtained from National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS). From NHTS dataset, a 2008 or 2009 model car owned by a household is extracted for estimation since this paper focuses on the analysis of consumers' new purchases (Liu 2014). The final sample includes 8086 purchases of 189 new vehicles.

Table 1 presents the summary statistics of vehicle characteristics for the 189 vehicles by vehicle type. Around 49% of new vehicles are passenger cars, and the rest 51% of them are vans, SUVs and light trucks. Price is the manufacturer's suggested retail price (MSRP) in dollars, and the average price of a new vehicle is $28,733. The average of horsepower per lbs. is 0.058; while passenger cars shows the highest horsepower per lbs., light trucks have lowest horsepower per lbs. Fuel economy is 21 miles per gallon on average; passenger car is much more efficient than vans, SUVs or light trucks. Footprint (square inch) is calculated by multiplying wheelbase by the average of front track width and rear track width. On average the footprint of a new vehicle is 6,800 square inch; and as expected the footprint of a light truck is the largest among the three vehicle types.

Table 1

Summary statistics of vehicle characteristics

	All classes		Passenger		Van & SUV		Light truck	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Price ($)	28732.9	15031.8	29864.8	18755.9	28816.3	10408.3	19565.0	4765.4
HP/weight	0.058	0.01	0.062	0.02	0.055	0.01	0.051	0.01
Footprint	6800.81	784.65	6448.74	586.01	7080.83	791.26	7459.30	881.46
MPG	21.05	4.49	23.22	4.62	19.04	3.32	18.81	2.80
# of vehicles	189		92		85		12	

Table 2 describes demographic characteristics of vehicle buyers by political geographic divisions. On average, a household in the sample has 3 family members, and its average income is about $88,000. Also, a household's average drive miles per year is estimated as 15K miles; east states, East North Central and East South Central drive the most. Regarding drivers' view on safety concerns in a household, it is '1' if safety is a little issue and '3' if it is a big issue. The average safety concerns in the sample is 2.3; and it is shown that drivers in the Mountain and

South areas like South Atlantic, East South Central and West South Central are more concerned about safety issue with high fatalities.

Table 2

Household demographics of vehicle buyers

	All states		New England		Middle Atlantic		East North Central		West North Central	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Household size	2.9	1.2	2.7	1.2	2.9	1.2	3.0	1.3	2.7	1.2
Income ($)	87914	33128	80661	31485	89046	33003	85613	33714	83288	32485
Annual miles	15030	10544	14520	10290	13756	9141	15853	11036	15338	13228
Safety concerns	2.3	0.7	2.0	0.7	2.2	0.7	2.2	0.7	2.1	0.7
Fatalities	1701	1076	134	96	1131	134	761	149	298	130
# of buyers	8086		204		1209		412		441	
	South Atlantic		East South Central		West South Central		Mountain		Pacific	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Household size	2.8	1.1	2.7	1.0	2.9	1.2	2.9	1.2	3.1	1.3
Income	84961	33572	80073	33286	90352	32227	90263	31917	94700	32891
Annual miles	15410	10589	17378	10474	15683	10934	14247	9658	14075	10003
Safety concerns	2.3	0.7	2.3	0.7	2.3	0.7	2.4	0.6	2.2	0.8
Fatalities	1463	746	942	84	3037	392	694	227	2937	638
# of buyers	2530		171		1682		437		1000	

Results

Table 3 shows consumers' preferences for vehicle attributes as results of the mixed logit model estimation. As expected, the price has significantly negative impacts on a consumer's choice of vehicle. The coefficient of ratio of horsepower to weight is positive and significant at 1% significance level, suggesting that consumers prefer a more powerful engine. The coefficients of fuel economy and footprint are also positive and significant. In sum, the estimation results imply that an average buyer prefers a vehicle with a less expensive price, a bigger size, a more powerful engine and a higher fuel efficiency.

To examine how the consumers' views on safety concerns affect their vehicle choices on the preference for vehicles' various attributes, this analysis includes interactions terms of footprint and weight with consumers' views on safety concerns. The result is also reported in Table 3. It suggests that consumers' safety concerns have significant impacts on their vehicle choices and their preference over safety-related vehicle characteristics. More safety concerns consumers have, they are more likely to prefer heavy vehicles but less likely to prefer big size cars, implying that buyers with high safety concerns seem to prefer cars produced by European manufacturers that are relatively small and heavy.

Table 3

Estimation results from the mixed logit model

choice	Mean	Std. Err.
Mean		
price (mean of log(coefficient))	-9.81684***	0.0870121
Horsepower/weight	23.78086***	3.01682
Footprint	0.0007129***	0.0000971
Miles per gallon	0.1189169***	0.0068802
Safety concern × weight	0.0000897**	0.0000386
Safety concern × footprint	-0.0000903**	0.0000461
Fatalities × footprint	7.05E-08***	2.27E-08
S.D.		
Price (S.D of log(coefficient))	0.5146929	0.0857968

Note: *, ** and *** denote significance at 10%, 5% and 1% respectively.

Weight and footprint are vehicles' attributes not only affecting traffic safety but also affecting fuel efficiency. For example, in general heavy vehicles are less efficient than light ones, so as the safety concerns grow, the buyers prefer heavy vehicles, and they are less probable to care about fuel efficiency. Meanwhile, the larger footprints are, buyers with less safety concerns are more likely to purchase the vehicles, indicating that the most recent CAFE would be good to both manufacturers producing larger vehicles and consumers in the sense that manufacturers can meet lower fuel economy standards under the CAFE, and consumers can decrease traffic safety risks.

Simulations

Understanding how consumers' vehicle choices respond to change in automakers' light weighting to improve fuel efficiency gives important implication for policies regarding energy and environmental issues. In this section, various simulations are conducted to see the impacts of automakers' possible strategies to meet the fuel efficiency standards on consumers' vehicle choices, market share and consumers' welfare.

The simulations focus on followings: New CAFE standards based on footprint will work favorably to domestic automakers compared to foreign automakers; Also, if the CAFE standards is stricter in the future, then some automakers would give up to meet the standards, but pay fine $55/mpg, then the change in market equilibrium price of cars is able to be simulated. For the simulation analysis, CAFE standards of different model years (1978-MY2011, MY2012, MY2017 and MY2015) for our vehicle samples are calculated based on formulas provided by EPA and Department of Transportation; Simulating scenarios on vehicles' weight upper bound, and lower bound will show the effects of automakers' light weighting on market share; Using total vehicle safety calculation in Li (2012), this paper demonstrates how consumers' demand on vehicle changes.

The simulation results implies that given the current technology, if the majority of fuel efficiency improvement comes from light weighting, the high fuel economy standard will possibly distort consumer choices and leads to lower consumer welfare. More specific results will be introduced in the conference.

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